Considerations of Oblique Impacts of Non-Spherical, Graphite-Epoxy Projectiles

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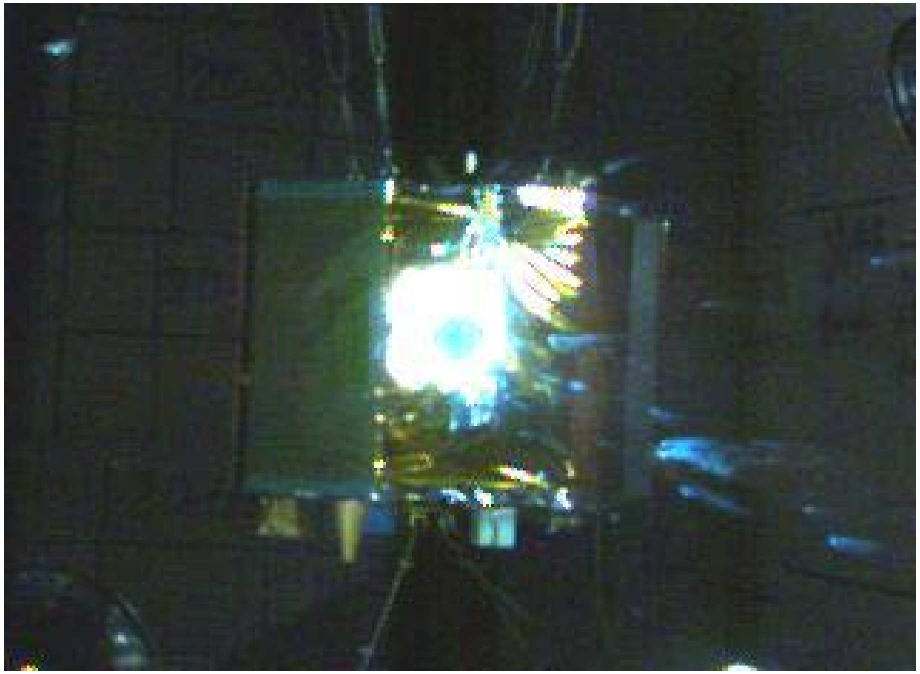
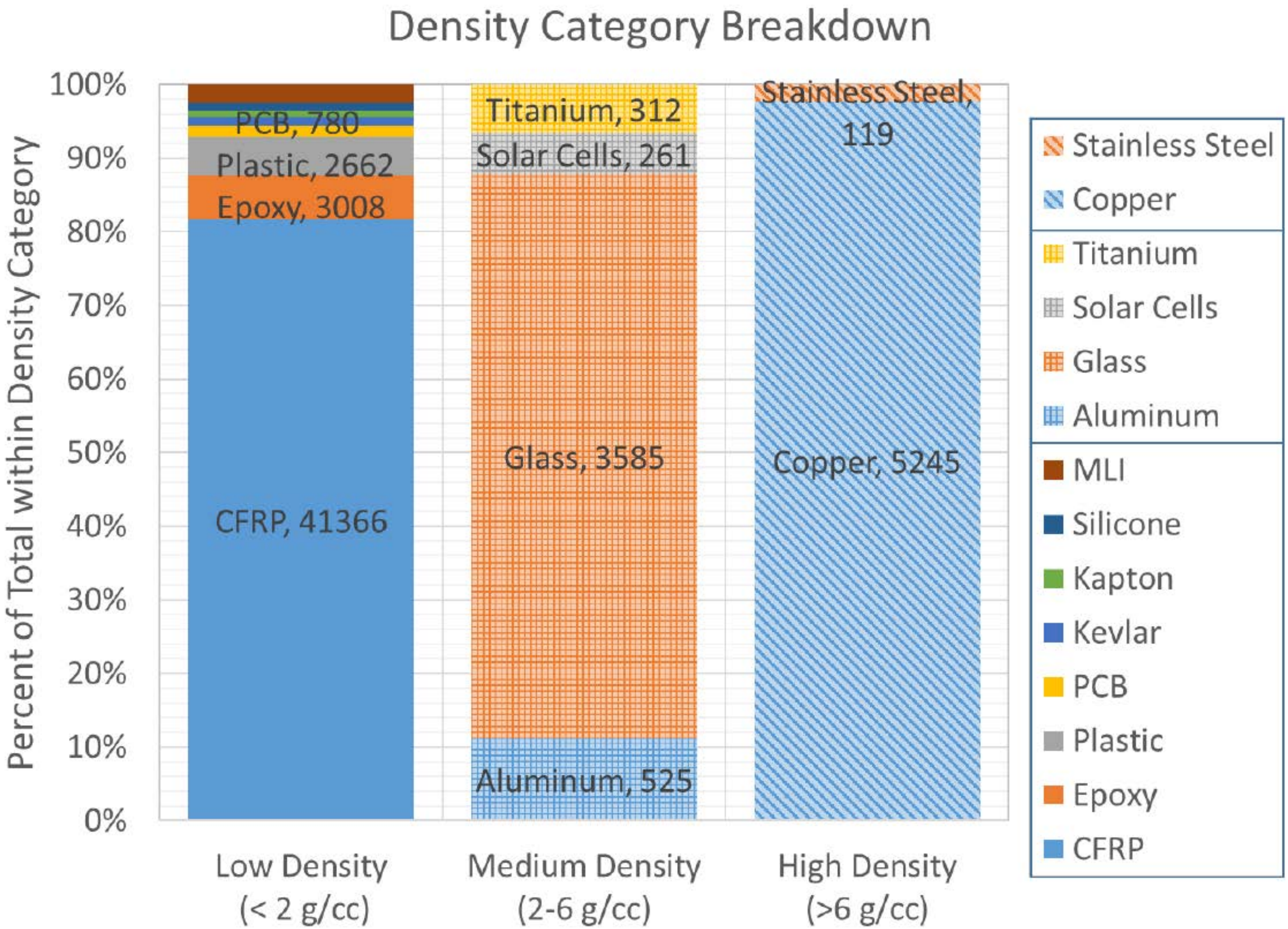


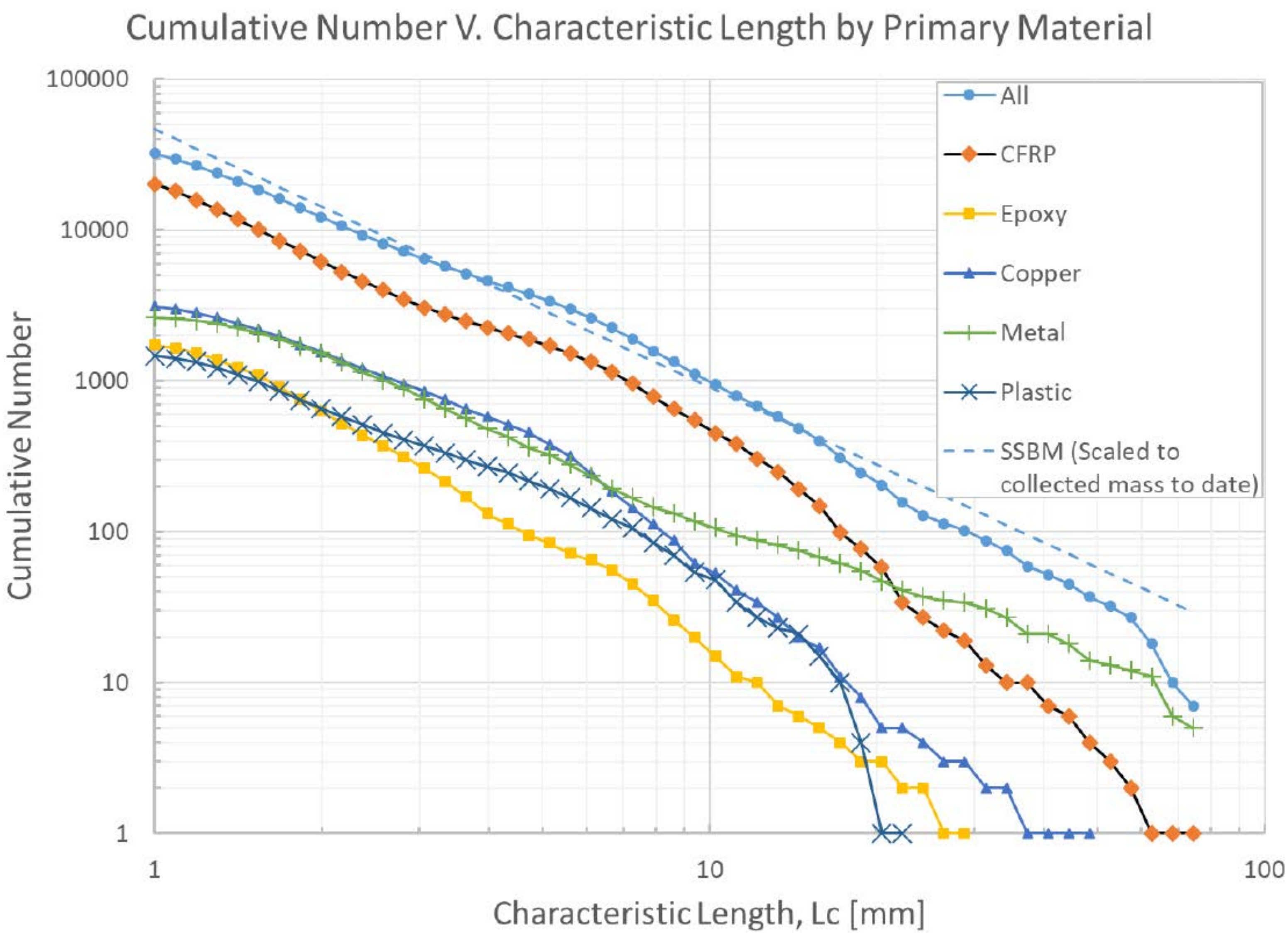
Orbital debris fragment shape study

- **The DebriSat experiment has greatly expanded NASA's understanding of large-scale, modern-construction, catastrophic satellite breakups**
  - Using modern materials DebriSat has pointed to a significant presence of carbon-fiber composite material in the sub-cm range.
  - Much of the carbon-fiber composite material had shapes that differed significantly from equidimensional shapes like spheres and cubes.
- **Impact experiments have generated validation data for numerical simulation models for an aluminum Whipple shield representative of shields in human space flight.**
  - Multiple Length to Diameter (L : D) ratios have been considered
  - Numerical simulation models have been developed that compare well against the obtained experimental data.
- **The numerical simulation models have been used to extrapolate away from the original data to develop impact models for shaped, carbon-fiber composites that includes impact obliquity for reliability assessments**

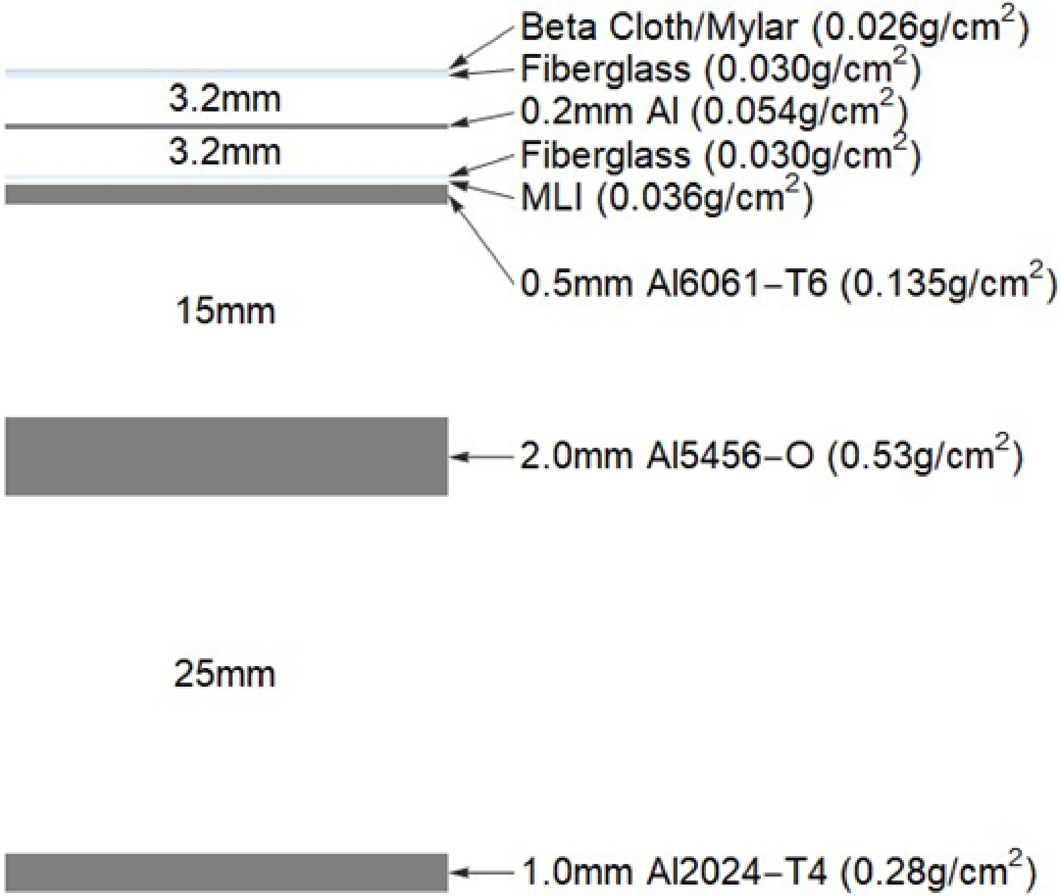
CFRP is a major debris component of a modern satellite break-up



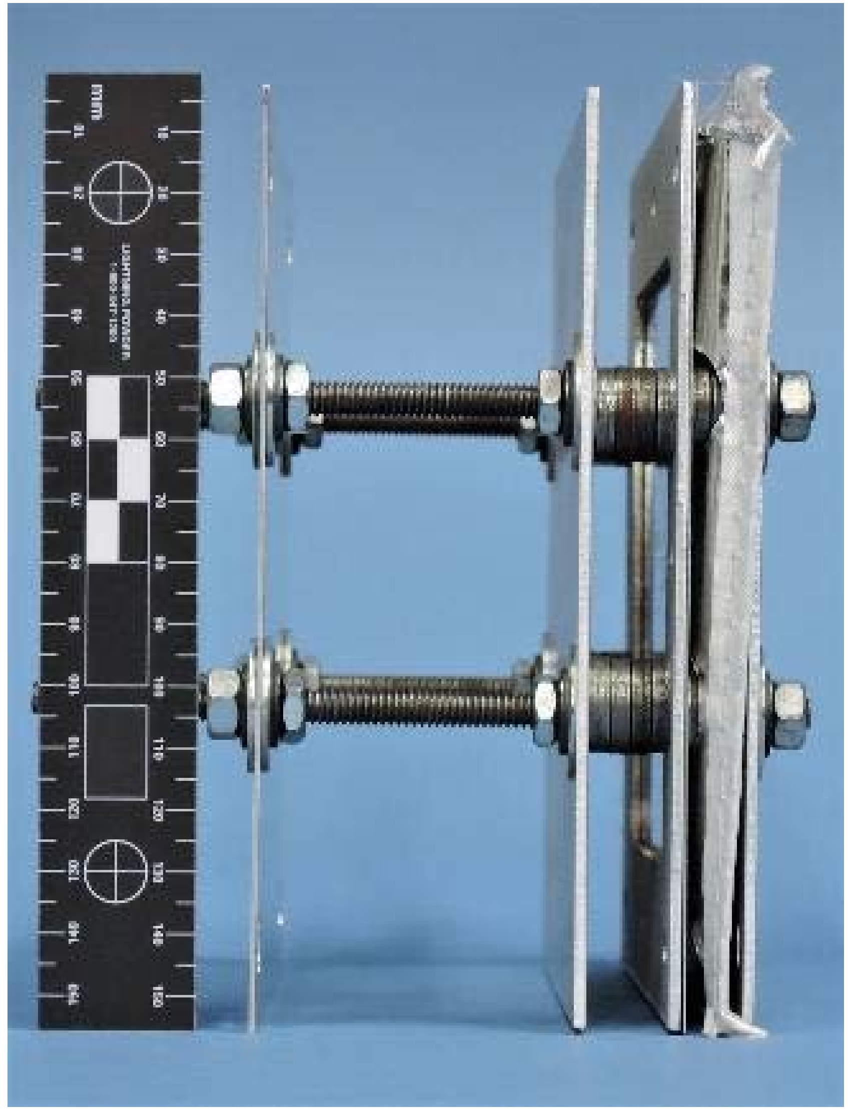
CFRP is the principal component of untrackable debris from a modern satellite break-up



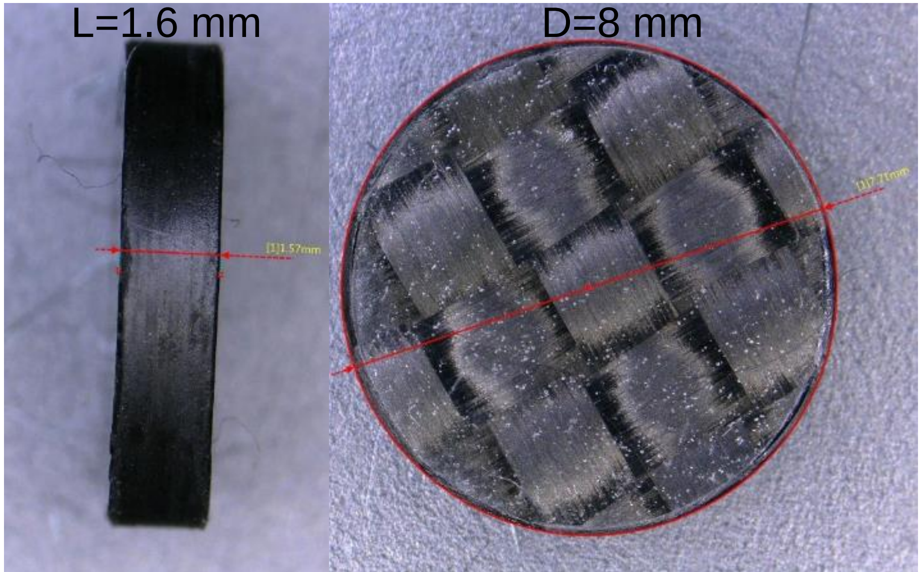
Impact experiments used a realistic Whipple shield with an external, thermal-blanket



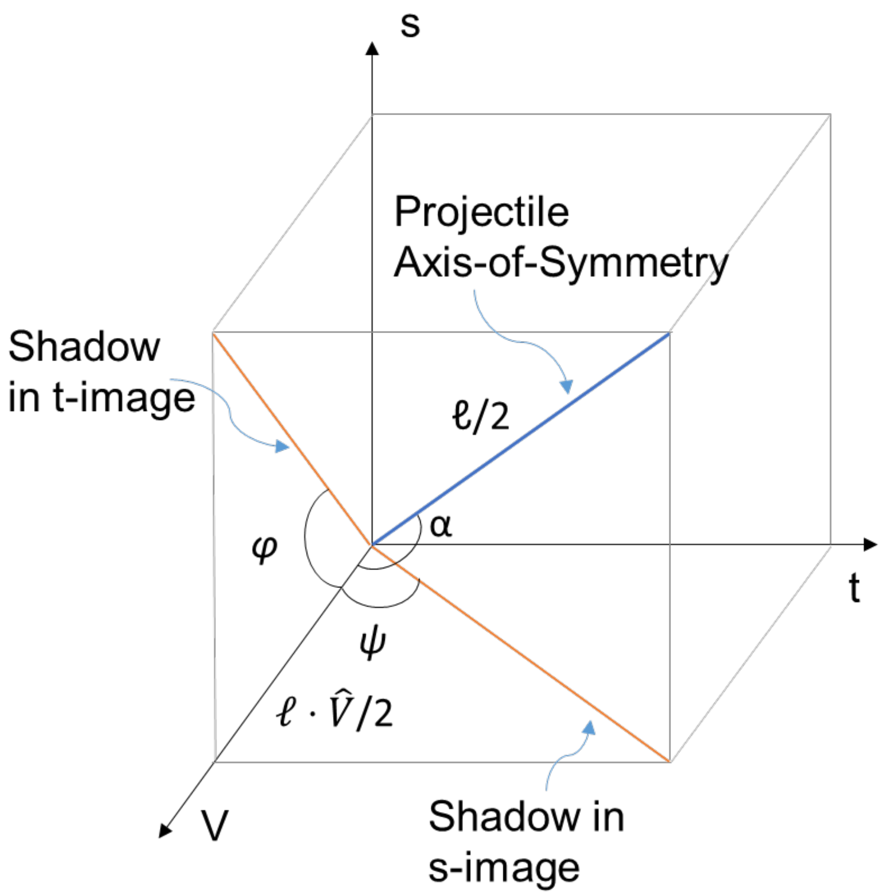
Schematic for experimental layup (layers scaled by mass; separations to scale), which represents a previously considered shield. [Lyons2013, Davis2013]

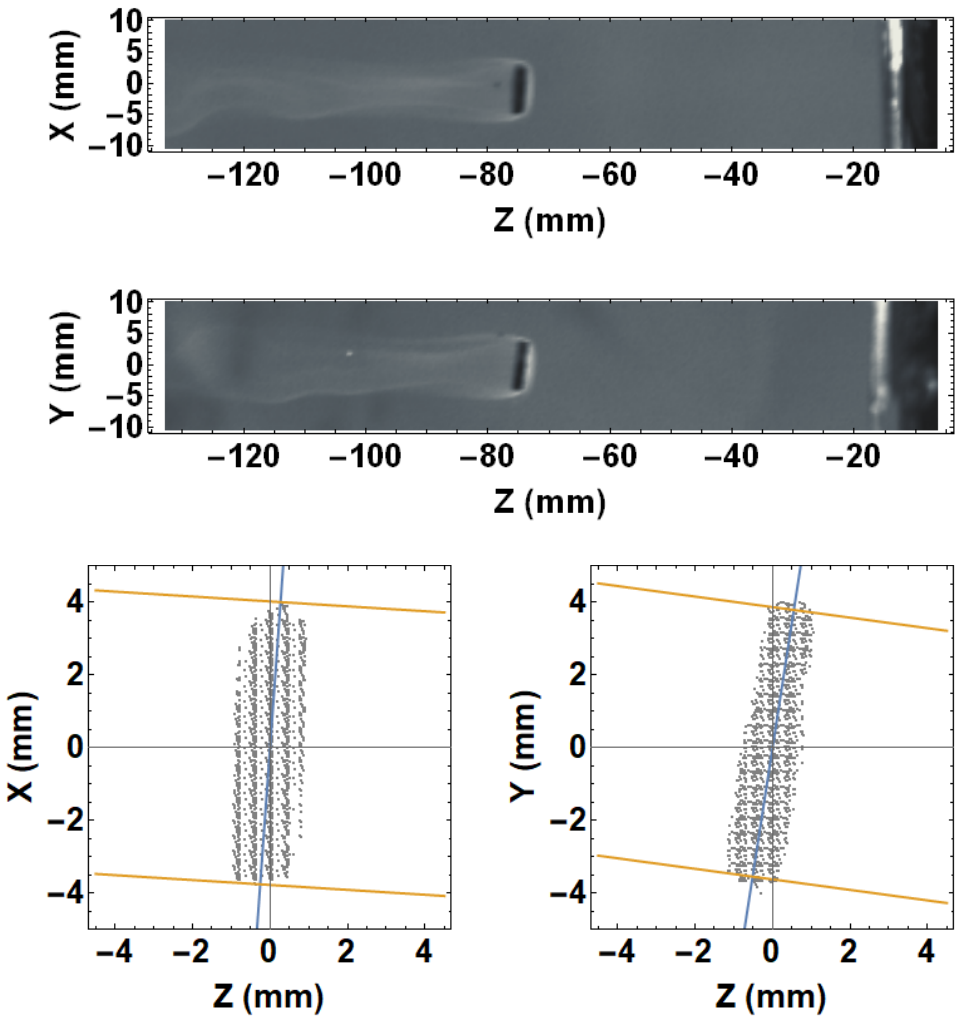


A total of eleven experiments have been considered with varying L : D aspect ratios



Orthogonal videocameras have been used to determine the projectiles orientation at impact

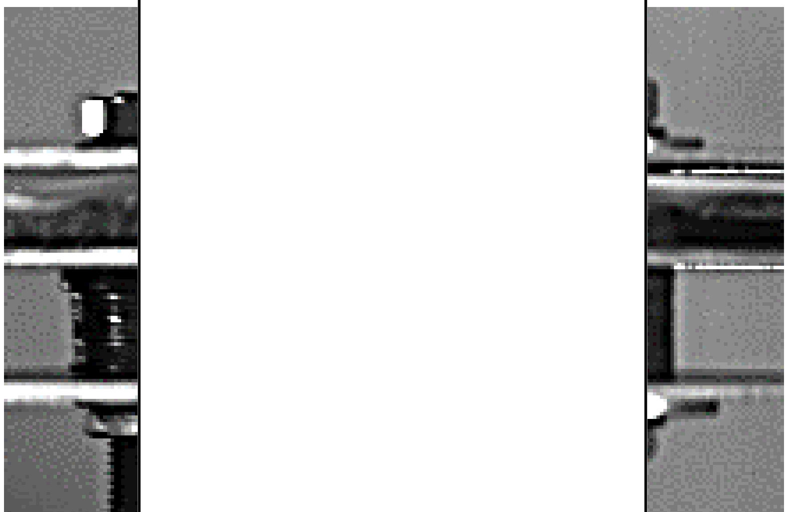




$$\alpha[\phi,\psi] = ArcCos\left[\sqrt{\frac{1}{1+Tan[\phi]^2+Tan[\psi]^2}}\right]$$

The experimental data is collected to assist in validation of numerical simulations

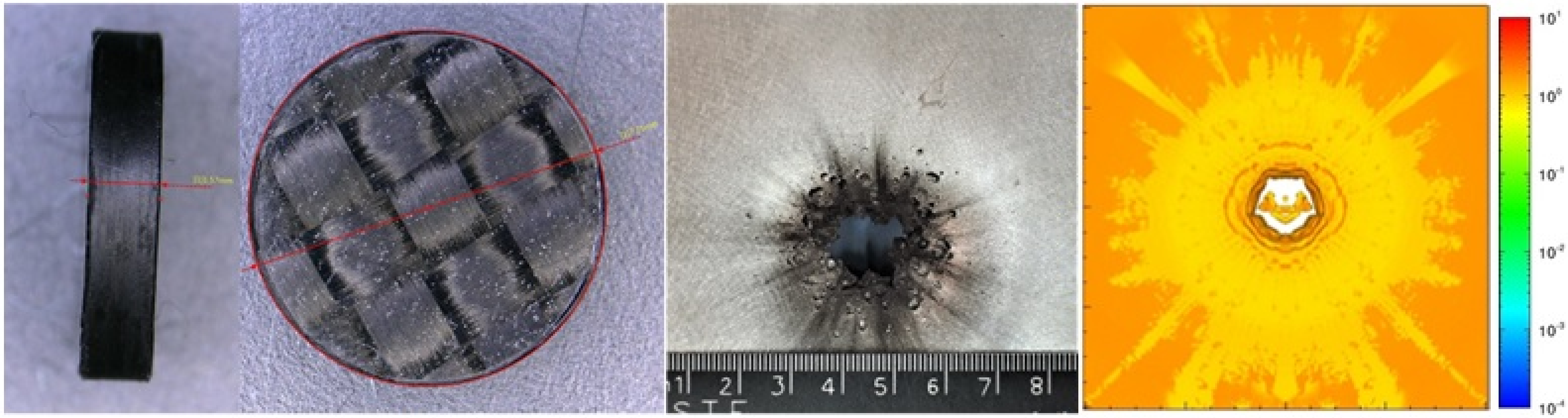
Impact: -2 μs to 28.5 μs



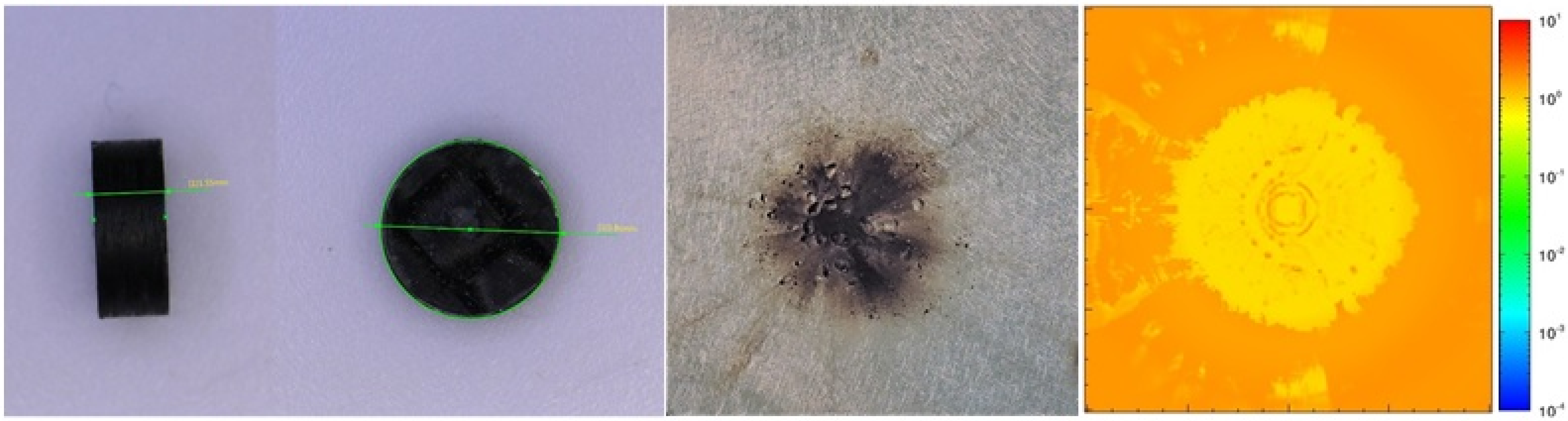
Simulation: 0 μs to 30 μs

Comparisons of experimental to simulation data for L : D < 1 (~flat disk)

L : D = 1.6 mm : 8.0 mm

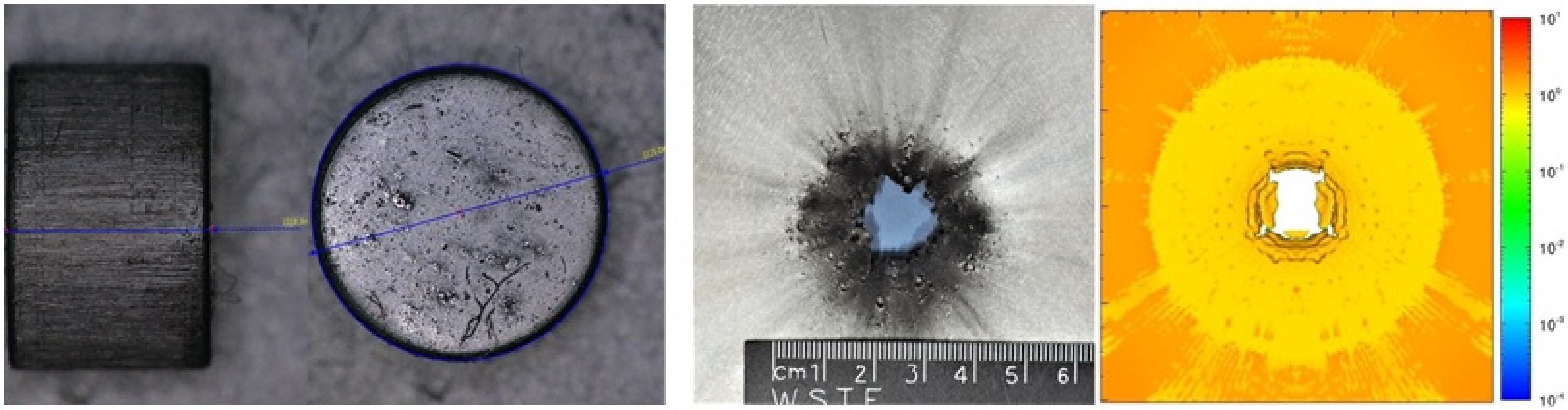


L : D = 1.6 mm : 4.0 mm

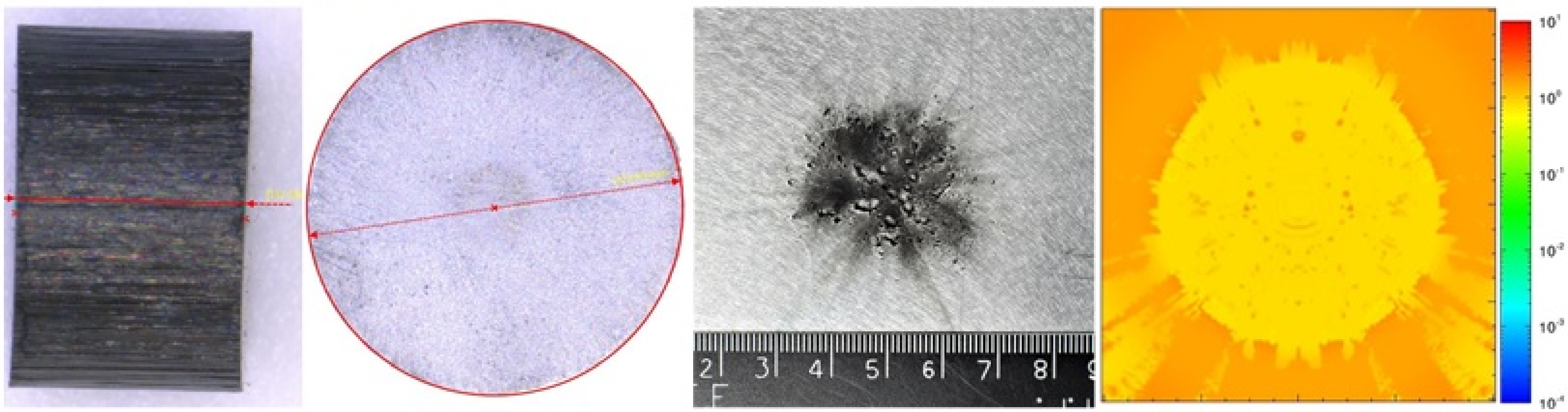


Comparisons of experimental to simulation data for L : D = 2/3 (mass equivalent to sphere)

L : D = 3.33 mm : 5.0 mm

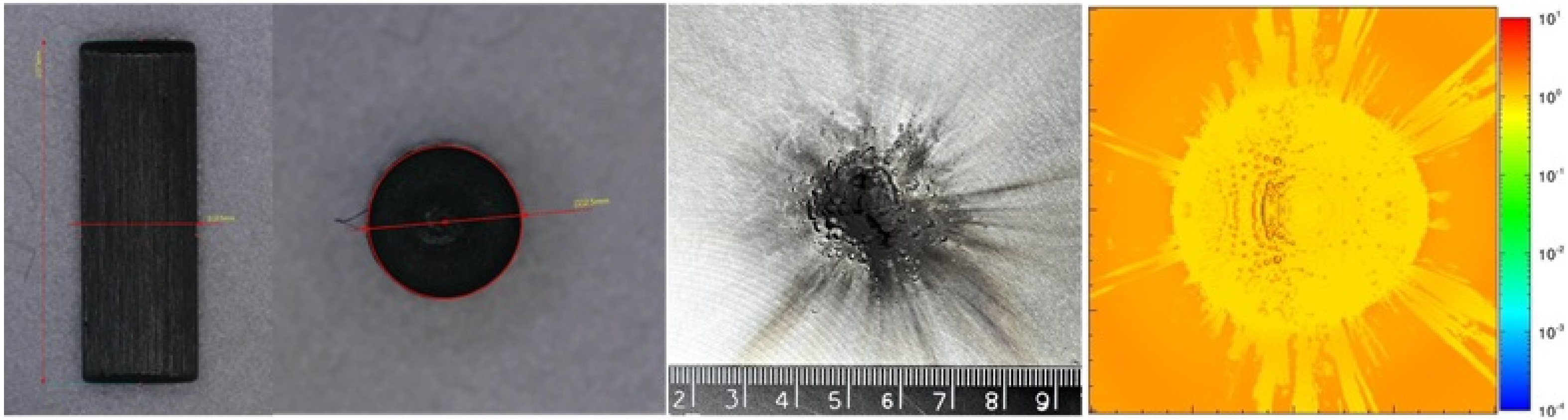


L : D = 2.3 mm : 3.45 mm

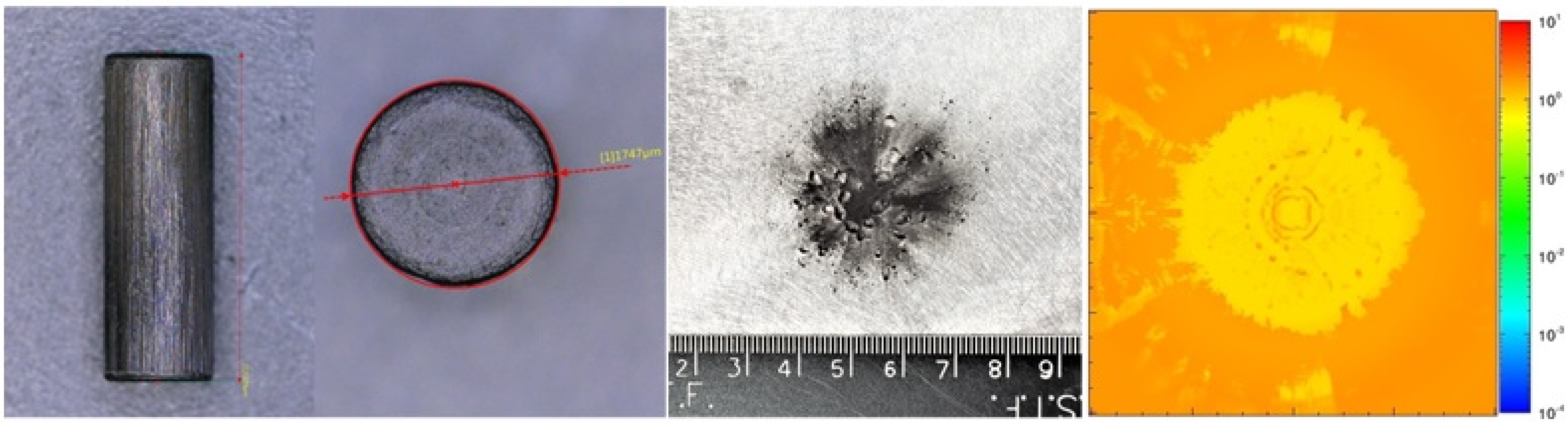


Comparisons of experimental to simulation data for L : D > 1 (~long rod)

L : D = 7.5 mm : 2.5 mm

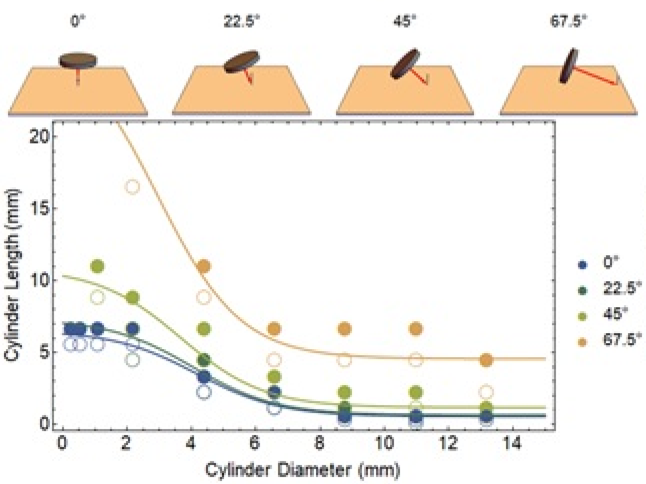


L : D = 5.25 mm : 1.75 mm

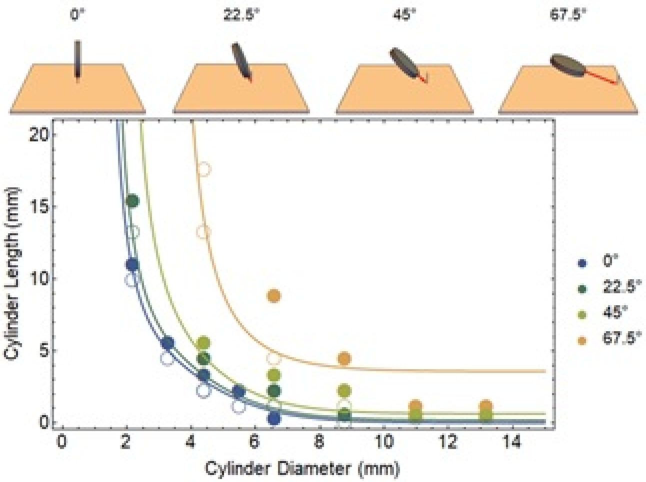


The critical length model for cylinders* has been adapted for unyawed, oblique impacts

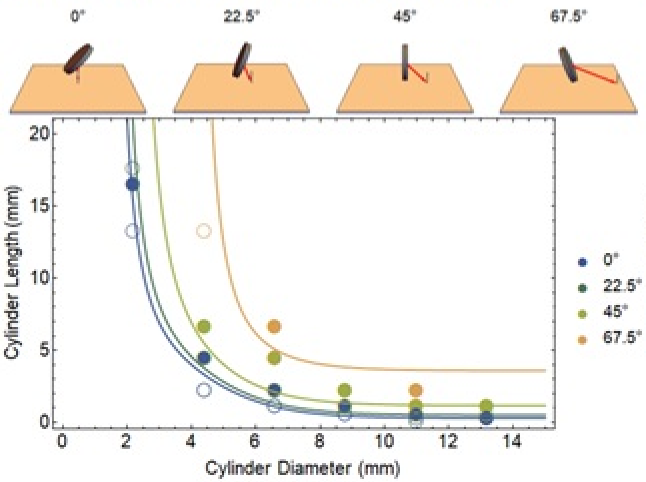
Central axis 0° to velocity vector



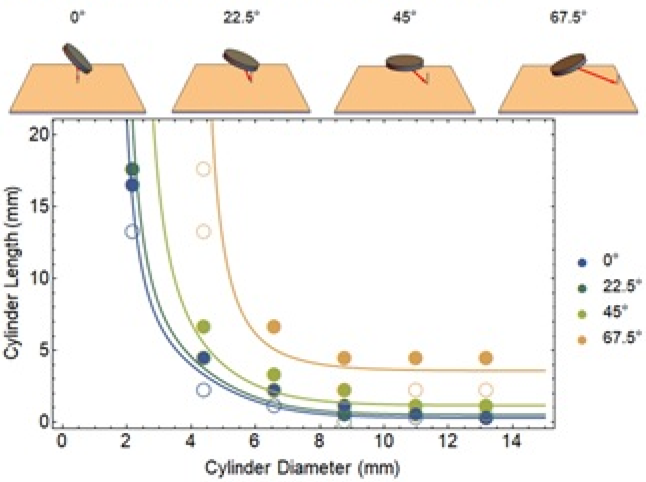
Central axis 90° to velocity vector



Central axis +45° to velocity vector



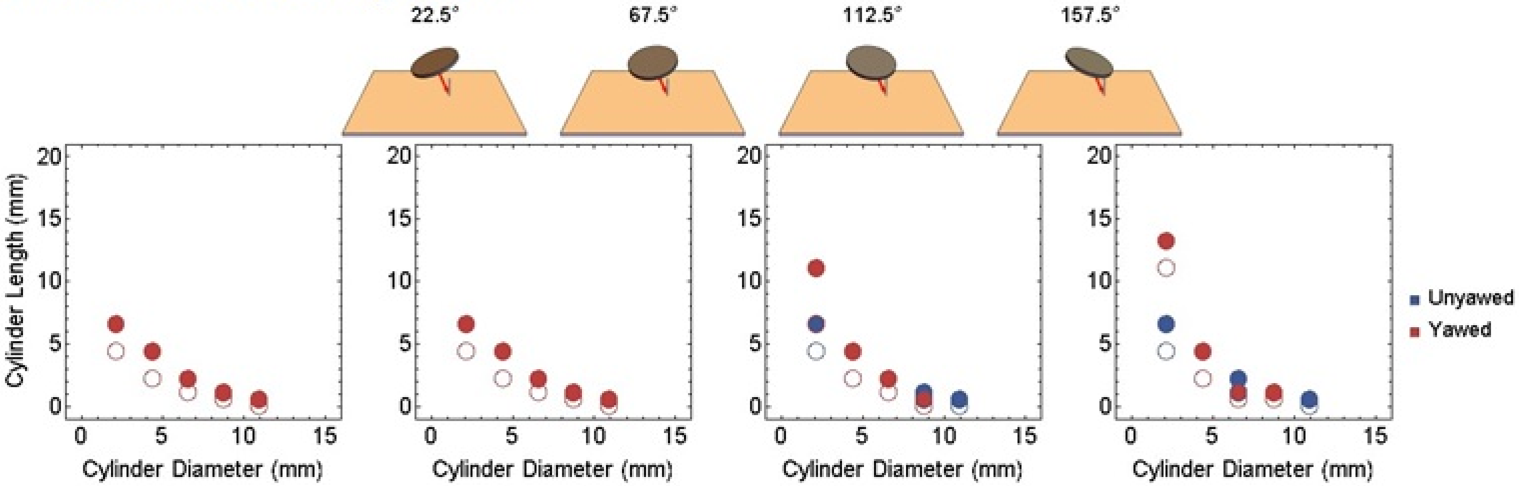
Central axis -45° to velocity vector



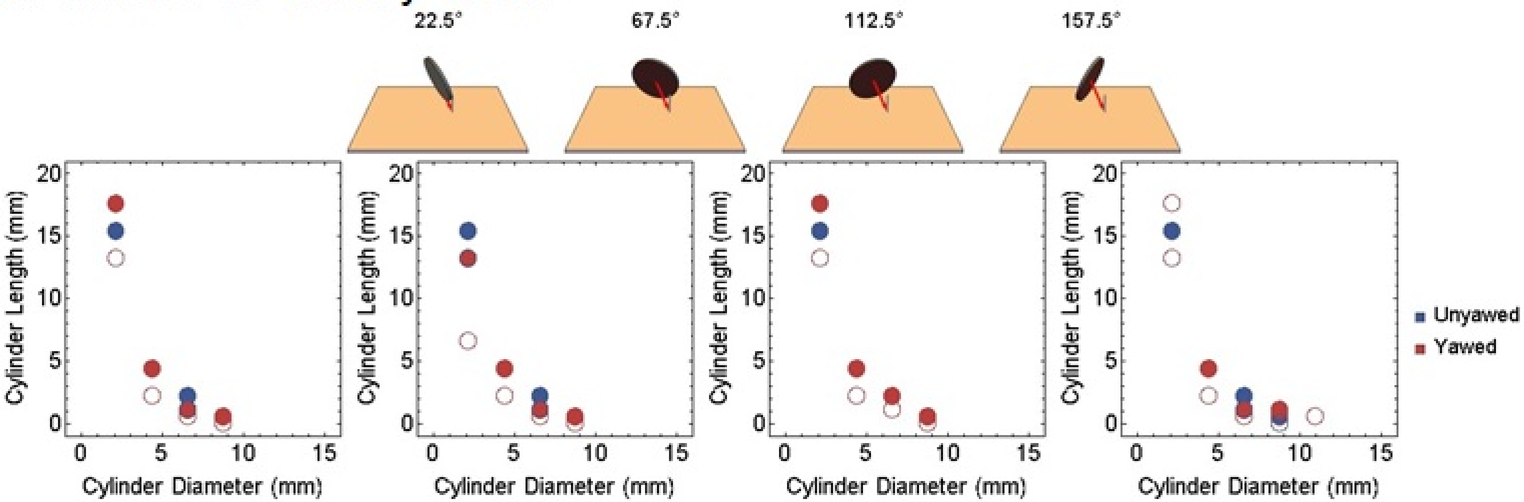
*Miller, J.E., Proceedings of the 2019 Hypervelocity Impact Society, Destin, FL, HVIS2019-044 (2019)

Simulations have been used to compare the yawed to unyawed for 22.5° oblique impacts

Central axis 0° to velocity vector

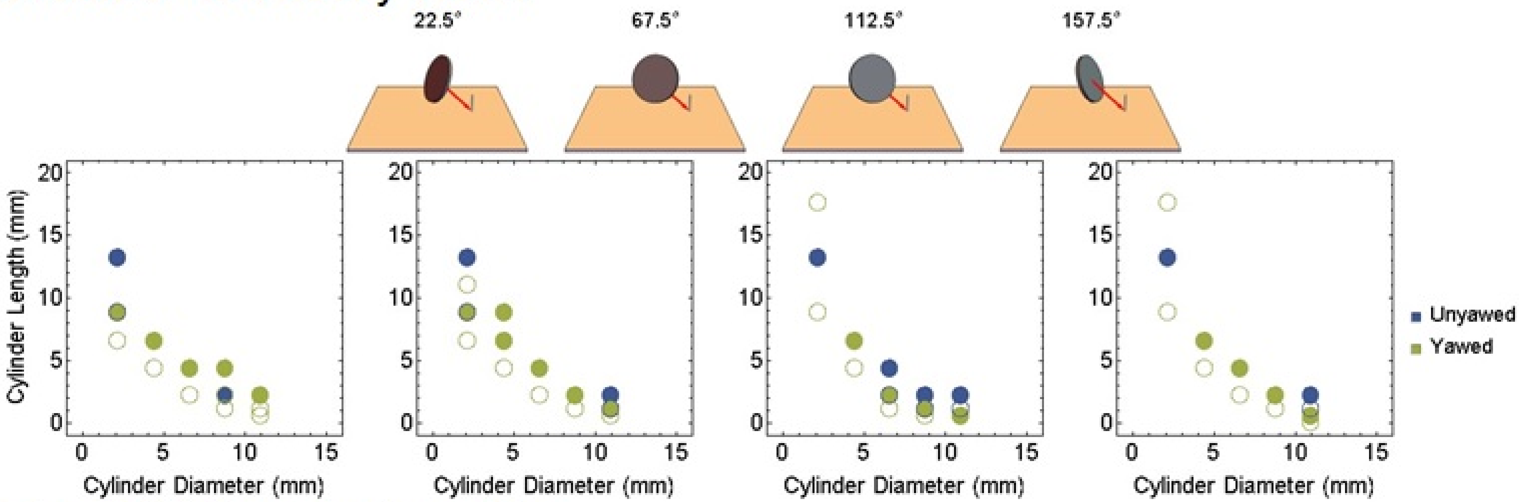


Central axis 90° to velocity vector

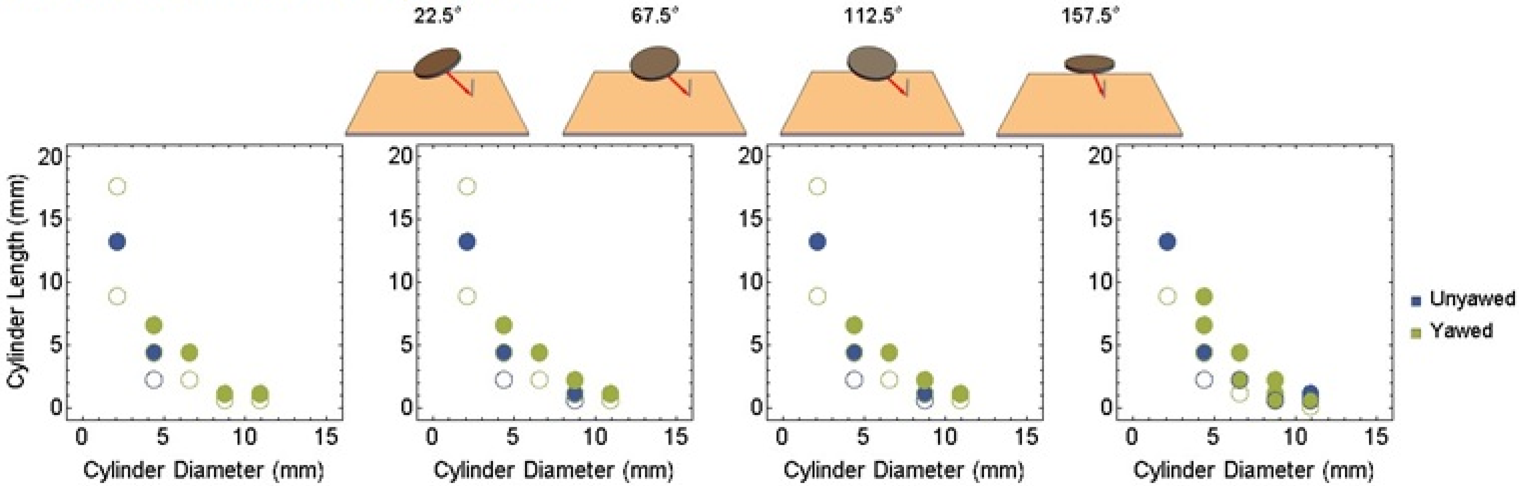


Simulations have been used to compare the yawed to unyawed for 45° oblique impacts

Central axis 0° to velocity vector



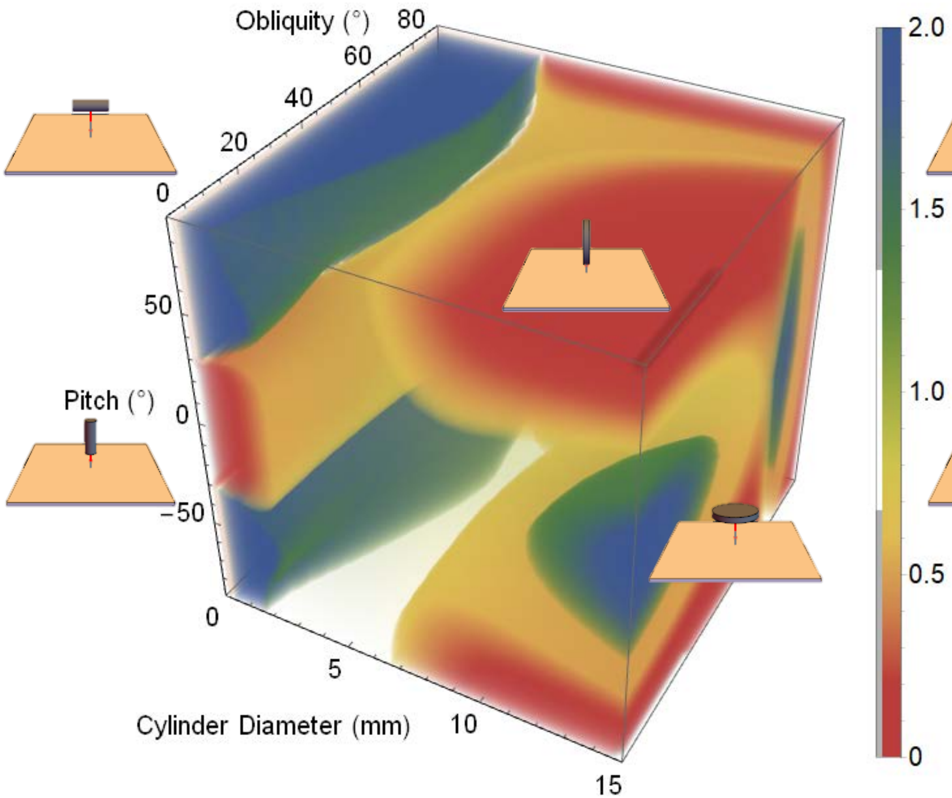
Central axis 90° to velocity vector



The critical cylinder length dependence can be used for other quantities of interest

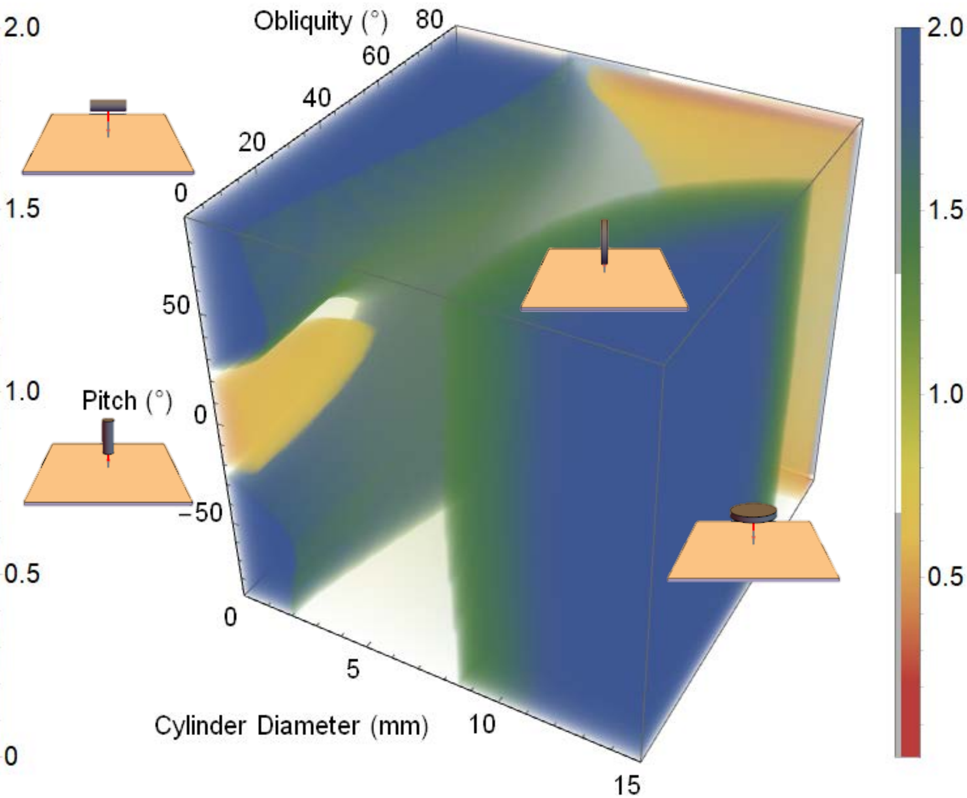
Critical cylinder to sphere mass

$$\frac{m_C}{m_S} = \frac{3}{2}\,\frac{{D_C}^2\, L_C}{{D_S}^3}$$



Critical cylinder to sphere average length

$$\frac{RCS_C}{RCS_S} = \frac{2D_C + L_C}{3D_S}$$



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